

EVALUATION OF THE SUSCEPTIBILITY CHART TO GRAVITATIONAL MASS MOVEMENTS USING GEOTECHNICAL SOIL CHARACTERIZATION TESTS

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The main cause of natural disasters in Brazil is gravitational mass movements, and among these, landslides stand out. In this context, the geomorphological region known as Serra do Mar, between the states of Paraná and natural disasters and, mainly, landslides, daily affect Rio de Janeiro. The Brazilian Geological Survey (SGB-CPRM) develops numerous programs, providing the community with products aimed at disaster prevention and urban planning. Among these, the Susceptibility Maps to Gravitational Mass Movements and Floods, which aim to analyse the degree of natural susceptibility of a terrain to the occurrence of gravitational mass movements and hydrological processes, such as floods, play an important role in municipal urban planning. This work aims to analyse the susceptibility map, by carrying out geotechnical characterization tests, seeking to confirm the assertive potential of the susceptibility map and its methodology. To this end, the study was based on soil characterization through tactile-visual field analyses and geotechnical characterization tests in the municipality of Itaóca, SP, in the region known as Vale do Ribeira and located in the Serra do Mar domain. The region was selected due to its geomorphology with steep slopes and numerous landslides recorded in the rainy event that occurred in January 2014, when torrential rains in the Guarda-Mão and Gurutuba river basins triggered a large number of landslides, causing debris flows and claiming approximately twenty-five lives in the municipality. Thus, the work allowed us to identify, in a pilot area, the usability of the susceptibility map to prevent disasters and plan the occupation of new areas in Brazilian municipalities.

Keywords: Soils; Susceptibility; Landslides.

1. Introduction

The Maps of Susceptibility to Gravitational Mass Movements and Floods are geotechnical documents (1:25,000) produced by the Brazilian Geological Survey (SGB-CPRM) in compliance with Federal Law 12.608/2012 and addressed to municipalities in the federation. These maps are important instruments in integrated actions for land use, urban development and environmental policies. They contain data that assist in urban planning, such as the hierarchy of susceptibility levels (high, medium and low), thus defining the most favourable terrains for occupation based on the possibility of being hit by natural disasters – landslides, floods, mass flows, flash floods and other related processes. In this context, municipalities throughout Brazil have been receiving assistance from the susceptibility maps produced by SGB-CPRM, and one of these municipalities was Itaóca (State of São Paulo) (Fig. 1), which produced its susceptibility map in 2018.

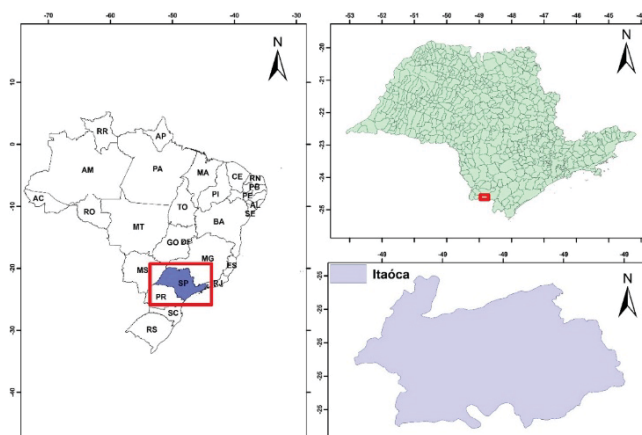


Fig. 1. Location map of the municipality of Itaóca.

Itaóca has attracted attention due to the events recorded in January 2014, when heavy rains led to hundreds of landslides on the slopes located in the northern part of the municipality. These landslides were caused by the geomorphology of the region, where mountainous terrain predominates, and caused debris to flow into the basins of the Guarda-Mão and Gurutuba rivers (tributaries of the Palmital River). As a result, these flows generated heavy downstream flooding and flooding, reaching the urban area of Itaóca. These events resulted in a large number of homeless and displaced people, dozens of deaths, and material damage.

2. Objectives

This paper will present the results of the Itaóca susceptibility map and these data will be compared with the results of geotechnical tests in a pilot area and with past events, with emphasis on those caused by torrential rains in January 2014. The aim is to compare and validate the results of the map in relation to susceptibility to flooding and mass movement, with the possibility of analysing the scars of mapped landslides.

3. Methods

There is a wide variety of methods and procedures available in the literature regarding the production of susceptibility zoning. However, aiming at a methodology that was practical and possible to be applied throughout the national territory in a short time and due to the great existing demand, the Institute of Technological Research (IPT) and the SGB-CPRM, in partnership, developed the methodology that was applied in Itaóca. This methodology was the basis for this work and is expressed in the document called "Cartas de Suscetibilidade a MovimentosGravitacionais de Massa e Inundações - 1:25,000: Nota TécnicaExplicativa" (Bitaret *et al.*, 2014). This methodology, in turn, was based on existing studies, such as the guide for zoning of susceptibility, hazard and risk to landslides (Fell *et al.*, 2008), prepared by the Technical Committee on Landslides and Engineered Slopes (Joint Technical Committee on Landslides and Engineered Slopes - JTC-1).

The methodology for producing susceptibility maps consists of three stages. The first is pre-field, where existing bibliography is analysed, with photointerpretation of orthophotos, to create a relief pattern map and mathematical models are created to define the susceptibility of the terrain, to both gravitational mass movements and floods. Basins susceptible to floods and mudflows are also predicted through mathematical models. DEM images with the best resolution available are used for these models, in addition to the registration of landslide scars, relief pattern maps and the HAND model for flooding. Later, in the second stage, these data are taken to the field, where SGB-CPRM teams, who cover the entire area of the municipality, validate them and, thus, the susceptibility maps to gravitational mass movements and floods are produced. In a third stage, in the office, with the consolidation of the data.

In order to compare the results obtained in the Itaóca susceptibility map, a pilot area where landslides occurred in January 2014 was selected. two trenches (T1 and T2) were dug at this location to obtain deformed and undeformed samples (Fig.2), and geotechnical tests were performed. These samples were obtained from portions of the slope where the susceptibility map indicated different classes, with T1 being an area of low susceptibility and T2 being a transition area between medium and high susceptibility to landslides (Fig. 3).

For the disturbed soil samples, granulometry tests with sedimentation and porosimetry with mercury intrusion were performed. The analyses of the undisturbed samples consisted of direct shear and vertical permeability tests, through the collection of undisturbed blocks of 30 cm x 30 cm. The collection of samples and all tests carried out followed the standards defined by the Brazilian Association of Technical Standards (ABNT), in the various standards that deal with the subject.

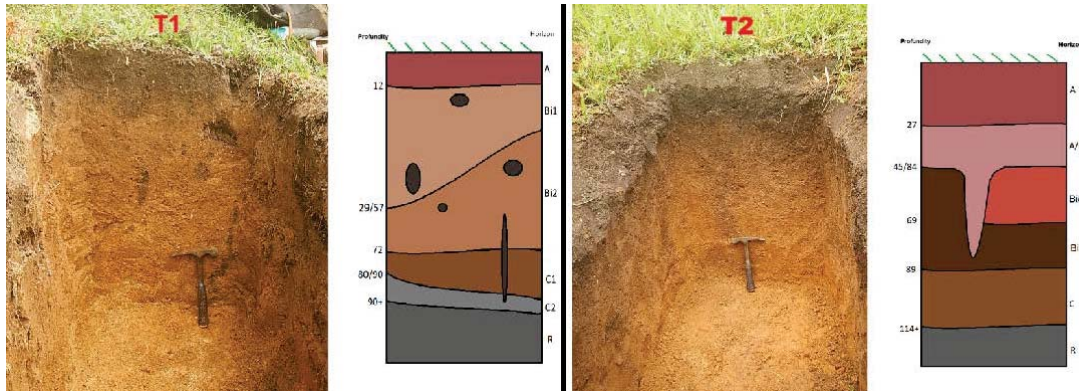


Fig. 2. Images of trenches T1 and T2 and schematic soil profiles.

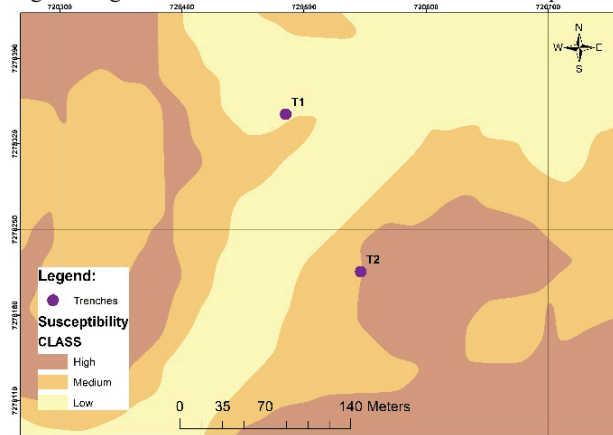


Fig. 3. Location of trenches for sample collection and susceptibility to landslides.

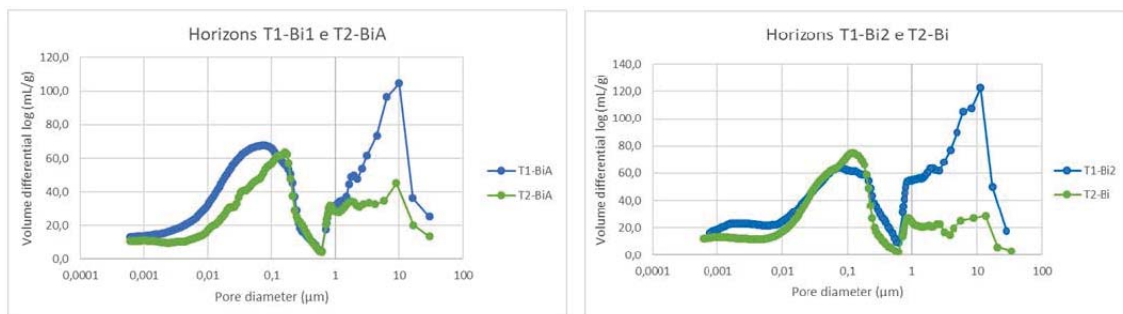
4. Results

The test results are presented by soil horizons, as shown in the following tables and graphs:

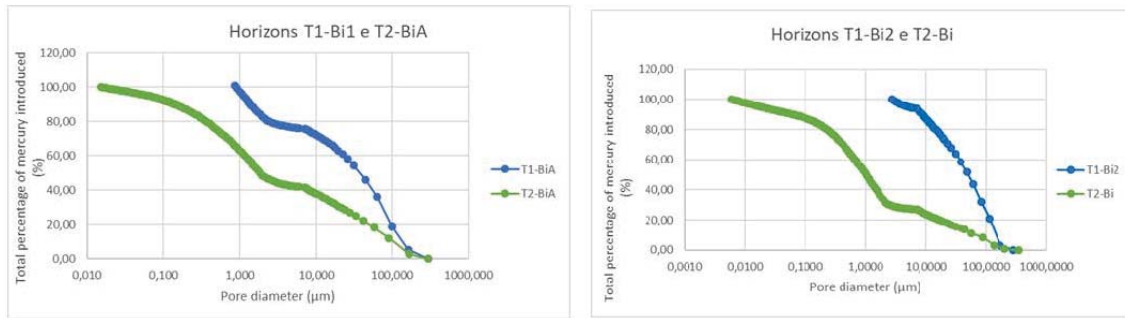
Table 1. Granulometry test with sedimentation.

Soil horizon*	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
T1-A	44,5	13,8	24,7	17,0
T1-Bi1	46,4	13,8	19,8	20,0
T1-Bi2	42,5	13,2	23,3	21,0
T1-C1	42,3	13,9	23,8	20,0
T1-C2	45,1	14,5	25,4	15,0
T2-A	56,7	13,6	17,7	12,0
T2-A/Bi	61,1	13,8	10,0	15,1
T2-Bi/A	51,7	15,9	21,4	11,0
T2-Bi	52,3	15,5	17,2	15,0
T2-C	52,1	14,0	17,9	16,0

* The sample nomenclature starts at T1 and T2 and refers, respectively, to trenches T1 and T2.



Graph 1. Pore diameter of the upper and deeper horizons of trenches T1 and T2.



Graph 2. Graphs showing the total percentage of mercury introduced and the pore size for the upper and deeper horizons of trenches T1 and T2.

The analysis of the mercury intrusion porosimetry test shows a quantity of macropores in the T2 samples, suggesting better drainage in this soil. The indication of a greater quantity of macropores in trench T2 is also validated when analysing the graph that relates the percentage of mercury intrusion with the pore diameter (Graph 2), where the T2-Bi/A and T2-Bi horizons show larger pores than in T1.

Table 2. Summary table of hydraulic conductivity values of vertical flow.

Trench	Soil Horizon	Vertical hydraulic conductivity (m/s)
T1	Bi1	$7,03 \times 10^{-05}$
	Bi2	$6,69 \times 10^{-05}$
T2	Bi/A	$5,01 \times 10^{-05}$
	Bi	$2,55 \times 10^{-04}$

Table 3. Summary table of direct shear test results.

Soil Horizon	Test	$\bar{\sigma}$ (°)	c'
T1-Bi1	Saturated not drained	24,3	23,3
	Natural humidity	15,6	42,6*
T1-Bi2	Saturated not drained	30,0	7,7
	Natural humidity	26,3	53,2*
T2-Bi/A	Saturated not drained	42,3	9,0
	Natural humidity	26,3	53,2*
T2-Bi	Saturated not drained	37,7	17,7
	Natural humidity	26,3	53,2*

*Apparent cohesion

Soil studies are complex due to the many variables that influence the formation of the pedological layer. The research does not intend to cover all soil analyses, but it defined tools to characterize the occurrence of landslides on a slope in the municipality of Itaóca, SP, with the aim of verifying the accuracy of the Itaóca susceptibility map, produced by the Geological Survey of Brazil.

Thus, the soils were evaluated in the field and laboratory, focusing on the characteristics that increase susceptibility to gravitational mass movements. Through granulometry, it was possible to classify these soils as HaplicCambisols, in trenches T1 and T2.

The soils in trenches T1 and T2 presented similar characteristics. However, T2 showed better drainage conditions, both in the permeability test (Table 2) and in the mercury intrusion porosimetry (graphs 1 and 2). In the direct shear test, all analyses showed low values for cohesion and friction angle, in addition to an abrupt drop between apparent cohesion (natural humidity) and cohesion when the soil is saturated, indicating great susceptibility to landslides in extreme rainfall conditions.

Thus, the study demonstrates the validity of the susceptibility map in indicating areas susceptible to landslides, but shows the need for caution when working with susceptibility classes (high, medium and low). This is because, when seeking greater details than the map scale indicates, this class limit may not be met accurately, since area T2 presented greater susceptibility to landslides, on the susceptibility map.

5. Conclusions

Mineralogical and geological differences, in addition to the shape of the slope, influence the susceptibility to penetration. The study proposed here proved the susceptibility to penetration of the proven slopes. The modelling used in the map showed coherence in indicating the susceptible areas, however, the definition of the susceptibility classes can evolve, emphasizing that a more detailed analysis, with the use of geotechnical tests, for example, may be necessary when there is a need for studies on a more detailed scale. However, it is clear that the susceptibility map is an important and necessary tool for municipal

urban planning and should always be used respecting its scale (1:25,000) and the scope of the map. Future studies can address restrictions not considered in this work and help to better understand the dynamics of gravitational mass movements, preventing or mitigating events similar to those that occurred in Itaóca in 2014.

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